RAMAN AMPLIFIER AND OPTICAL COMMUNICATION SYSTEM

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a Raman amplifier that can compensate attenuation which a signal suffers when it is transmitted in an optical communication system.

Description of the Background Arts

In an optical communication system, a signal lights suffers attenuation when transmitted in an optical transmission line, and consequently its power decreases when it reaches a receiver. If the power of signal lights which have reached a receiver is less than a given value, the performance of normal optical communication cannot be achieved. Therefore, it is necessary to provide an optical amplifier between a transmitter and a receiver in order to compensate such transmission attenuation.

As for such optical amplifier, there are a rare earth element doped optical fiber amplifier using a rare-earth-doped optical fiber for amplification and a Raman amplifier using Raman amplification phenomenon in an optical fiber. The characteristic of the Raman amplifier is that its spectrum band having gain can be shifted by the wavelength of pump light.

In a Wavelength Division Multiplexing (WDM) optical communication system, a Raman amplifier is required to amplify signal lights in a wide spectrum band or a plurality of spectrum bands. For example, in Literature (1): [Y. Emori, et al. "100nm bandwidth flat gain Ra

and gain-equalized by 12-wavelength-channel WDM high power laser diodes", OFC '99, PD19 (1999), there is disclosed a Raman amplifier in which an attempt was made to expand the width of the wavelength having gain by introducing pump light of 12 different wavelengths into a single test fiber (i.e., an optical fiber for Raman amplification).

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a gain module and a Raman amplifier of low cost and an optical communication system in which a wavelength width having gain is broad.

In order to achieve this object, a gain module according to the present invention is provided with (1) a plurality of optical fibers which differ from each other with respect to the composition of their respective optical regions and through which signal lights are amplified by stimulated Raman scattering and (2) one or more pump light sources which supply each of the optical fibers with pump light for Raman amplification. In this specification, a region (region inside the mode field diameter) in which optical power is equal to or more than e^{-2} of the optical power in the core center is called an "optical region." The term “Raman amplification” as used herein means amplifying signal lights by stimulated Raman scattering.

In one embodiment of the present invention, the difference of the Stokes shift of optical fibers may be equal to or more than 200 cm^{-1} or not less than 400 cm^{-1}. A plurality of optical fibers for Raman amplification may be connected in series or in parallel. The pump light source may supply pump light of a

substantially identical wavelength or pump light of a different wavelength to each of the optical fibers. Also, the pump light source may supply pump light from one common pump light source. The optical region in some of the optical fibers may be doped with GeO_2 or P_2O_5.

An optical communication system according to an embodiment of the present invention is provided with optical transmission lines composed of a plurality of optical fibers installed in station sections the optical regions of which optical fibers differ from each other with respect to their composition and through which signal lights are amplified by stimulated Raman scattering.

An optical communication system according to another embodiment of the present invention is provided with optical transmission lined composed of a plurality of optical fibers being located at a station the optical regions of which optical fibers differ from each other with respect to their composition and through which signal lights are amplified by stimulated Raman scattering.

The above and further objects and novel features of the invention will be more fully clarified from the following detailed description when the same is read in connection with the accompanying drawings. It is to be expressly understood, however, that the drawings are for the purpose of illustration only and are not intended as a definition of the limits of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic diagram of a gain module 10 according to a first embodiment of the present invention.

Raman scattering intensity with respect to each composition of optical fibers.

Figure 3 is a graph showing the relationship between the wavelength of pump light and the gain of Raman amplification.

Figure 4 is a schematic diagram of a gain module 20 according to a second embodiment of the present invention.

Figure 5 is a schematic diagram of a gain module 30 according to a third embodiment of the present invention.

Figure 6 is a schematic diagram of a gain module 40 according to a fourth embodiment of the present invention.

Figure 7 is a schematic diagram of an optical communication system 1 according to an embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following, preferred embodiments of the present invention will be explained in detail with reference to the accompanying drawings. To facilitate the comprehension of the explanation, the same reference numerals denote the same parts, where possible, throughout the drawings, and a repeated explanation will be omitted. The dimensions in the drawings are partly exaggerated and do not always correspond to actual ratios of dimensions.

(First embodiment of the gain module)

Figure 1 is a schematic diagram of a gain module 10 according to a first embodiment of the present invention. The gain module 10 is provided with a first optical fiber 11_1 for Raman amplification, a first multiplexer/demultiplexer

and a second multiplexer/demultiplexer 12_2 from an input end 10a to an output end 10b in the enumerated order. In addition, the gain module 10 is provided with a pump light source 14 that is connected to both the first multiplexer/demultiplexer 12_1 and the second multiplexer/demultiplexer 12_2.

The pump light source 14 outputs pump light for Raman amplification. The first multiplexer/demultiplexer 12_1 supplies the pump light to the first optical fiber 11_1 for Raman amplification. It also allows the signal lights, which have reached it from the first optical fiber 11_1 for Raman amplification, to pass to the optical isolator 13. The second multiplexer/demultiplexer 12_2 supplies the pump light to the second optical fiber 11_2 for Raman amplification. It also allows the signal lights, which have reached it from the second optical fiber 11_2 for Raman amplification, to pass toward the output end 10b. The multiplexer/demultiplexer 12_1 may be a fiber optic coupler, interference filter, or planer waveguides.

The first optical fiber 11_1 for Raman amplification transmits signal lights, which have been input from the input end 10a, toward the first multiplexer/demultiplexer 12_1, and also Raman-amplifies the signal lights as a result of the pump light being supplied thereinto. The optical isolator 13 allows light to pass in the direction from the first multiplexer/demultiplexer 12_1 to the second optical fiber 11_2 for Raman amplification, but does not allow the light to pass in the opposite direction. The second optical fiber 11_2 for Raman amplification transmits signal lights, which have been input from the optical isolator 13, toward the second multiplexer/demultiplexer 12_2, and amplifies the signal lights as a result of the pump light being supplied thereinto.

The pump light that has been output from the pump light source 14 is branched into two to be supplied to the first optical fiber 11_1 for Raman amplification via the first multiplexer/demultiplexer 12_1 and to the second optical fiber 11_2 for Raman amplification via the second multiplexer/demultiplexer 12_2. Then, the signal lights, which have been input to the input end 10a, propagate through the first optical fiber 11_1 for Raman amplification while they are being Raman-amplified, pass through the first multiplexer/demultiplexer 12_1 and the optical isolator 13, then propagate through the second optical fiber 11_2 for Raman amplification while they are being Raman-amplified, and are emitted from the output end 10b via the second multiplexer/demultiplexer 12_2.

The two optical fibers 11_1 and 11_2 for Raman amplification differ from each other with respect to the composition of their respective optical region and they are connected in series. Pump light having a substantially identical wavelength that has been output from the common pump light source 14 is supplied to each of these optical fibers. Because the respective Stokes shift of these optical fibers differs from each other, the gain of Raman amplification is in a different wavelength range in each of these optical fibers.

Figure 2 is a graph showing the relationship between Stokes shift and Raman scattering intensity with respect to each composition of the optical fibers. The Stokes shift in which Raman scattering intensity becomes the maximum differs depending on the composition. For example, in the case of GeO_2, the Raman scattering intensity becomes the greatest when the Stokes

the Stokes shift of about 635 cm^{-1}. In the case of B_2O_3, the intensity becomes the greatest at the Stokes shift of about 825 cm^{-1}. When such Stokes shift is expressed in terms of a wavelength unit, in the case of GeO_2, it is 100 nm, in the case of P_2O_5, 140 nm, and in the case of B_2O_3, 180 nm, with respect to the pump light of 1400 nm, respectively.

Figure 3 is a graph showing the relationship between the wavelength of pump light and the gain of Raman amplification. Figure. 3 (a) shows that the Stokes shift of the first optical fiber 11_1 for Raman amplification is a, and that the optical fiber 11_1 has gain, centering around the wavelength that is longer than the wavelength λ of the pump light by a. Similarly, Fig. 3 (b) shows that the second optical fiber 11_2 for Raman amplification has gain, centering around the wavelength that is longer than the wavelength λ of the pump light by b. In this case, when the first optical fiber 11_1 for Raman amplification and the second optical fiber 11_2 for Raman amplification are connected in series so as to constitute the gain module 10, and the pump light of wavelength λ is supplied to the optical fibers 11_1 and 11_2 for Raman amplification, as shown in Fig. 3 (c), the gain of the gain module 10 equals the sum of each gain of the optical fibers 11_1 and 11_2 for Raman amplification.

For example, the first optical fiber 11_1 for Raman amplification may be a silica-based optical fiber whose optical region was doped with GeO_2, and the second optical fiber 11_2 for Raman amplification may be a silica-based optical fiber whose optical region is doped with P_2O_5. In this way, the first optical fiber for Raman amplification will have gain, centering around the wavelength

wavelength (1400 nm), and the second optical fiber for Raman amplification will have gain, centering around the wavelength (Stokes shift quantity of 635 cm^{-1}) which is 140 nm longer than the pump light wavelength. Then, the gain module 10 will have gain in a wavelength range which includes both wavelengths (Stokes shift quantity difference of 215 cm^{-1}) which are longer than the pump light wavelength by 100 nm and 140 nm, respectively, and consequently will be able to amplify the signal lights in a broader wavelength range (not less than 200 cm^{-1}) than in the conventional case where only one kind of optical fiber for Raman amplification is used.

The first optical fiber 11_1 for Raman amplification may be placed in a transmission line that connecting a transmitting station, a receiving station, and a repeater station with each other, or may be installed in the form of coils inside a station. The second optical fiber 11_2 for Raman amplification preferably may be installed in the form of coils inside a station.

As described above, the gain module 10 according to the first embodiment is able to achieve the expansion of the wavelength width for Raman amplification gain by using only one pump light source, and has the advantage of low cost as compared with the Raman amplifier described in Literature (1) in which an attempt is made expand the wavelength width for gain by providing many pump light sources.

Also, in the present embodiment, an optical multiplexer and demultiplexer are unnecessary because the first optical fiber 11_1 and the second optical fiber 11_2 are connected in series, and hence a Raman amplifier can be made at a cost lower than in the case of parallel connection.

(Second embodiment of the gain module)

Figure 4 is a schematic diagram of a gain module 20 according to a second embodiment of the present invention. The gain module 20 is provided with a first optical fiber 21_1 for Raman amplification, a second optical fiber 21_2 for Raman amplification, and a first multiplexer/demultiplexer 22_1, in the enumerated order from an input end 20a to an output end 20b. The gain module 20 is also provided with a pump light source 24 that is connected with a first multiplexer/demultiplexer 22_1. A Raman amplifier 26 is provided with this gain module 20, control unit 25, and a second multiplexer/demultiplexer 22_2.

The pump light source 24 outputs pump light for Raman amplification. The first multiplexer/demultiplexer 22_1 supplies pump light to both the first optical fiber 21_1 for Raman amplification and the second optical fiber 21_2 for Raman amplification, and allows signal lights, which have reached it from the second optical fiber 21_2 for Raman amplification, to pass toward the output end 20b.

Signal lights which are input to the input end 20a are demultiplexed by the second multiplexer/demultiplexer 22_2 and a power of a predetermined wavelength signal light is monitored by a control unit 25. The control unit 25 controls the pump light source 24 such that the output power of the gain module 20 may be a predetermined value.

The first optical fiber 21_1 for Raman amplification transmits signal lights, which have been input from the input end 20a, toward the second optical fiber 21_2 for Raman amplification, and also Raman-amplifies the signal lights as a

result of pump light being supplied thereinto. The second optical fiber 21_2 for Raman amplification transmits signal lights, which have been input from the first optical fiber 21_1 for Raman amplification, toward the first multiplexer/demultiplexer 22_1, and also Raman-amplifies the signal lights as a result of pump light being supplied thereinto.

In the gain module 20, the pump light that has been output from the pump light source 24 is supplied to both the first optical fiber 21_1 for Raman amplification and the second optical fiber 21_2 for Raman amplification via the first multiplexer/demultiplexer 22_1. Then, the signal lights that have been input to the input end 20a propagate through the first optical fiber 21_1 for Raman amplification and the second optical fiber 21_2 for Raman amplification while they are being Raman-amplified, and are emitted from the output end 20b via the first multiplexer/demultiplexer 22_1.

In the gain module 20, the two optical fibers 21_1 and 21_2 for Raman amplification differ from each other with respect to the composition of their respective optical region, and they are connected in series. Pump light of substantially identical wavelength that has been output from the common pump light source 24 is supplied to each of them. Because their respective Stokes shift differs from each other, they have the gain of Raman amplification in a different wavelength range, respectively.

For example, the first optical fiber 21_1 for Raman amplification may be a silica-based optical fiber whose optical region is doped with GeO_2, and the second optical fiber 21_2 for Raman amplification may be a silica-based optical

fiber for Raman amplification has gain, centering around the wavelength (Stokes shift quantity 420 cm^{-1}) which is 100 nm longer than the pump light wavelength (1400 nm), and the second optical fiber for Raman amplification has gain, centering around the wavelength (Stokes shift quantity 825 cm^{-1}) which is 180 nm longer than the pump light wavelength. Then, the gain module 20 has gain in the range which includes both of the wavelengths (Stokes shift quantity difference 405 cm^{-1}) which are longer than the pump light wavelength by 100 nm and 180 nm, and signal lights can be amplified in a broader wavelength range (equal to or more than 400 cm^{-1}) than the conventional case in which only one kind of optical fiber for Raman amplification is used. The first optical fiber 21_1 for Raman amplification and the second optical fiber 21_2 for Raman amplification may be installed in a transmission line that connects a transmitting station, a receiving station, and a repeater station with each other, or they may be placed in the form of coils in a station. The gain module 20 has a similar effect as the gain module 10 according to the first embodiment.

(Third embodiment of the gain module)

Figure 5 is a schematic diagram of a gain module 30 according to a third embodiment of the present invention. The gain module 30 is provided with a first optical fiber 31_1 for Raman amplification, a first multiplexer/demultiplexer 32_1, an optical isolator 33, a second optical fiber 31_2 for Raman amplification, and a second multiplexer/demultiplexer 32_2 from an input end 30a to an output end 30b in the enumerated order. The gain module 30 is also provided with a

multiplexer/demultiplexer 32_1 and a second pump light source 34_2 that is connected to a second multiplexer/demultiplexer 32_2. A Raman amplifier 36 is provided with this gain module 30, control unit 35, and a third multiplexer/demultiplexer 32_3

The first pump light source 34_1 and the second pump light source 34_2, respectively, output pump light for Raman amplification. The first multiplexer/demultiplexer 32_1 supplies pump light, which has been output from the first pump light source 34_1, to the first optical fiber 31_1 for Raman amplification, and also allows signal lights, which have reached it from the first optical fiber 31_1 for Raman amplification, to pass toward the optical isolator 33. The second multiplexer/demultiplexer 32_2 supplies pump light, which has been output from the second pump light source 34_2, to the second optical fiber 31_2 for Raman amplification, and also allows signal lights, which have reached it from the second optical fiber 31_2 for Raman amplification, to pass toward the output end 30b.

Signal lights which are output from the output end 20b are demultiplexed by the third multiplexer/demultiplexer 32_3 and a power of a predetermined wavelength signal light is monitored by a control unit 35. The control unit 35 controls the pump light source 34_2 such that the output power of the gain module 30 may be a predetermined value.

The first optical fiber 31_1 for Raman amplification transmits signal lights, which have been input from the input end 30a, toward the third multiplexer/demultiplexer 32_1, and also Raman-amplifies the signal lights as a result of pump light being supplied thereinto. The optical isolator 33 allows

light to pass in the direction from the first multiplexer/demultiplexer 32_1 to the second optical fiber 31_2 for Raman amplification but does not allow the light to pass in the opposite direction. The second optical fiber 31_2 for Raman amplification transmits signal lights, which have been input from the optical isolator 33, toward the second multiplexer/demultiplexer 32_2, and also Raman-amplifies the signal lights as a result of pump light being supplied thereinto.

In the gain module 30, the pump light that has been output from the first pump light source 34_1 is supplied to the first optical fiber 31_1 for Raman amplification, and the pump light that has been output from the second pump light source 34_2 is supplied to the second optical fiber 31_2 for Raman amplification. Then, signal lights that have been input to the input end 30a propagate through the first optical fiber 31_1 for Raman amplification while they are being Raman-amplified, pass through the first multiplexer/demultiplexer 32_1 and the optical isolator 33, propagate through the second optical fiber 31_2 for Raman amplification while they are being Raman-amplified, and are emitted from the output end 30b via the second multiplexer/demultiplexer 32_2.

Especially, in the gain module 30, the two optical fibers 31_1 and 31_2 for Raman amplification differ from each other with respect to the composition of their respective optical region, and they are connected in series. Because the optical fibers 31_1 and 31_2 for Raman amplification differ from each other with respect to the composition of their respective optical region including a core region, their Stokes shifts differ from each other. By way of example, the first optical fiber 31_1 for Raman amplification may be a silica-based optical fiber whose optical region is doped with GeO_2, and the second optical fiber 31_2 for

Raman amplification may be a silica-based optical fiber whose optical region is doped with P_2O_5.

The wavelength λ_1 of the pump light supplied to the first optical fiber 31_1 for Raman amplification and the wavelength λ_2 of the pump light supplied to the second optical fiber 31_2 for Raman amplification may be identical or may differ from each other.

When the wavelength λ_1 and the wavelength λ_2 are the same, the optical fibers 31_1 and 31_2 for Raman amplification have the gain of Raman amplification respectively in a different wavelength range as in the case of the first or second embodiment. As a result, the gain module 30 can amplify signal lights in a wavelength range broader than in the conventional case that uses only one kind of an optical fiber for Raman amplification.

On the other hand, when the wavelength λ_1 and wavelength λ_2 are different from each other, the gain module 30 has the gain of Raman amplification within a wavelength range according to respective compositions of the optical fiber 31_1 and 31_2 for Raman amplification and the wavelength of the pump light. By choosing a suitable wavelength of pump light, the respective wavelength ranges having the gain of Raman amplification of the optical fibers 31_1 and 31_2 for Raman amplification can be further separated from each other or can partly overlap each other. (Refer to Fig. 3 (d)). As a result, the expansion and adjusting of the wavelength range having gain can easily be done.

The first optical fiber 31_1 for Raman amplification and the second optical

connecting a transmitting station, a receiving station, and a repeater station each other, or they may be placed in the form of coils in a station.

As described above, the gain module 30 according to the present embodiment is advantageous in that the expansion and adjustment of the wavelength width having the gain of Raman amplification can be done by using only two pump light sources and hence is low cost.

(Fourth embodiment of the gain module)

Figure 6 is a schematic diagram of a gain module 40 according to a fourth embodiment of the present invention.

The gain module 40 is provided with a first optical fiber 41_1 for Raman amplification and a second optical fiber 41_2 for Raman amplification which are connected together in parallel, and a demultiplexer 45 is positioned between these optical fibers and an input end 40a. Furthermore, between these optical fibers and an output end 40b there are provided multiplexer/demultiplexers 42_1 and 42_2 and an optical multiplexer 46. In addition, the gain module 40 is provided with a pump light source 44 that is connected to both the first multiplexer/demultiplexer 42_1 and the second multiplexer/demultiplexer 42_2.

The pump light source 44 outputs pump light for Raman amplification. The first multiplexer/demultiplexer 42_1 supplies pump light to the first optical fiber 41_1 for Raman amplification, and also allows signal lights, which have reached it from the first optical fiber 41_1 for Raman amplification, to pass toward the optical multiplexer 46. The second multiplexer/demultiplexer 42_2 supplies pump light to the second optical fiber 41_2 for Raman amplification, and also allows signal lights, which have reached it from the second optical fiber 41_2

for Raman amplification, to pass toward the optical multiplexer 46.

The demultiplexer 45 demultiplexes signal lights, which have been input from an input end 40a, into a first spectrum band and a second spectrum band, and outputs the signal lights in the first spectrum band to the first optical fiber 41_1 for Raman amplification and outputs the signal lights in the second spectrum band to the second optical fiber 41_2 for Raman amplification. The first optical fiber 41_1 for Raman amplification transmits the signal lights in the first spectrum band toward the first multiplexer/demultiplexer 42_1, and also Raman-amplifies the signal lights as a result of pump light being supplied thereinto. The second optical fiber 41_2 for Raman amplification transmits signal lights in the second spectrum band toward the second multiplexer/demultiplexer 42_2, and also Raman-amplifies the signal lights as a result of pump light being supplied thereinto. The optical multiplexer 46 multiplexes the signal lights in the first spectrum band and the signal lights in the second spectrum band, and outputs the multiplexed signal lights toward the output end 40b.

In the gain module 40, the pump light that has been output from the pump light source 44 is branched into two to be supplied to the first optical fiber 41_1 for Raman amplification and the second optical fiber 41_2 for Raman amplification. Then, the signal lights that have been input into an input end 40a are demultiplexed by the demultiplexer 45 into a first spectrum band and a second spectrum band. The signal lights in the first spectrum band propagate through the first optical fiber 41_1 for Raman amplification while they are being

multiplexer/demultiplexer 42_1. The signal lights in the second spectrum band propagate through the second optical fiber 41_2 for Raman amplification while they are being Raman-amplified and travel toward the optical multiplexer 46 via the second multiplexer/demultiplexer 42_2. The signal lights in the first and second spectrum bands are multiplexed by the optical multiplexer 46 and are emitted from the output end 40b.

Especially, in the gain module 40, the two optical fibers 41_1 and 41_2 for Raman amplification differ from each other with respect to the composition of their respective optical region, and they are connected in parallel. Each of these optical fibers is supplied with pump light of a substantially identical wavelength that has been output from a common pump light source 44. Because their respective Stokes shift differs from each other, their gain of Raman amplification respectively is in a different wavelength range.

By way of example, the first optical fiber 41_1 for Raman amplification may be a silica-based optical fiber whose optical region is doped with GeO_2, and the second optical fiber 41_2 for Raman amplification may be a silica-based optical fiber whose optical region is doped with P_2O_5. The first optical fiber 41_1 for Raman amplification and the second optical fiber 41_2 for Raman amplification may preferably be placed in the form of coils in a station. In the present embodiment, pump light of a substantially identical wavelength is supplied to both of the optical fibers 41_1 and 41_2 for Raman amplification, but pump light for Raman amplification of a different wavelength may be supplied to each of them.

The gain module 40 also can attain the gain of Raman amplification in a

wider wavelength range, using only one pump light source and hence is of low cost as compared with the Raman amplifier that is equipped with numerous pump light sources as described in Literature (1).

(Embodiment of optical communication system)

Figure 7 is a schematic diagram of an optical communication system 1 according to an embodiment of the present invention. The optical communication system 1 is composed of optical transmission lines connecting a transmitting station 61 and a repeater station 62, a repeater station 62 and a repeater station 63, and a repeater station 63 and a receiving station 64 (A section between these stations is generically called a "station section").

The optical transmission line between the transmitting station 61 and the repeater station 62 is made of an optical fiber 51_1 for Raman amplification. The optical transmission line between the repeater station 62 and the repeater station 63 is made of optical fibers 51_2 and 51_3 for Raman amplification. The repeater station 62 is provided with a pump light source 54_1 that outputs pump light for Raman amplification and a multiplexer/demultiplexer 52_1 for introducing the pump light, which has been output from the pump light source 54_1, into the optical fiber 51_1 for Raman amplification. The repeater station 63 is provided with a pump light source 54_2 that outputs pump light for Raman amplification and a multiplexer/demultiplexer 52_2 for introducing the pump light, which has been output from the pump light source 54_2, into the optical fibers 51_2 and 51_3 for Raman amplification. That is, the optical fiber 51_1 for

fibers 51_2 and 51_3 for Raman amplification, the pump light source 54_2, and the multiplexer/demultiplexer 52_2 constitute a gain module.

In the optical communication system 1, the pump light for Raman amplification that has been output from the pump light source 54_1 in the repeater station 62 is supplied to the optical fiber 51_1 for Raman amplification via the multiplexer/demultiplexer 52_1. The pump light that has been output from the pump light source 54_2 in the repeater station 63 is supplied to the optical fibers 51_2 and 51_3 for Raman amplification via the multiplexer/demultiplexer 52_2. Then, signal lights that have been output from the transmitting station 61 propagate through the optical fiber 51_1 for Raman amplification toward the repeater station 62 while they are being Raman-amplified, and further propagate through the optical fibers 51_2 and 51_3 for Raman amplification toward the repeater station 63 while they are being Raman-amplified, and further propagate through the optical transmission line to the receiving station 64 until they are received at the receiving station 64.

Especially, in the optical communication system 1, the three optical fibers 51_1 through 51_3 for Raman amplification differ from each other with respect to the composition of their respective optical region, and they are connected in series. Pump light of a substantially identical wavelength that has been output from the common pump light source 54_2 is supplied to each of these optical fibers. Because their respective Stokes shift differ, they have the gain of Raman amplification in different wavelength ranges, respectively.

By way of example, any one of the optical fibers 51_1 through 51_3 for

optical region is doped with GeO_2, and any one of the other optical fibers preferably may be a silica-based optical fiber whose optical region is doped with P_2O_5. The gain of Raman amplification of the optical communication system 1 is the sum of each gain of the optical fibers 51_1 through 51_3 for Raman amplification, and accordingly the wavelength width having gain can be further broadened as compared with the case of a conventional optical communication system that is provided with only one kind of optical fiber for Raman amplification. As described above, the optical communication system 1 according to the present embodiment is low cost because the wavelength width that has the gain of Raman amplification can be expanded by using only three pump light sources.

In the present embodiment, the optical fiber for Raman amplification is